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**GB 0852836**
**US 4080709**
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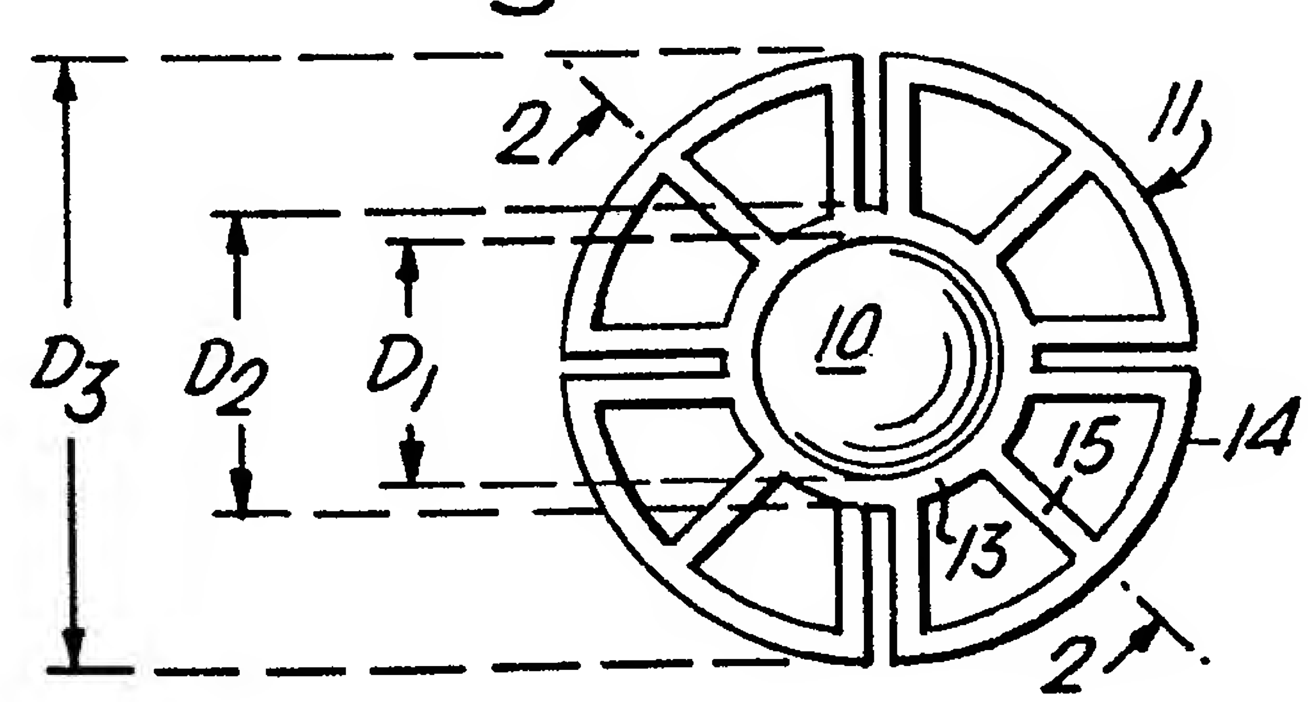
(54) **Intraocular and extraocular lens construction and making by selective erosion**

(57) A unitary lens and haptic construction integrally formed by selective erosion from the same sheet of starting material, comprising a relatively thick rigid central lens component having a generally circular periphery, and relatively thin pliant generally annular outer haptic component extending radially outward of and distributed circumferentially about the lens periphery.

Erosion may be effected by chemical etching, plasma-ion discharge or photo-etching.

Fig.1.




The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy

Fig.1.

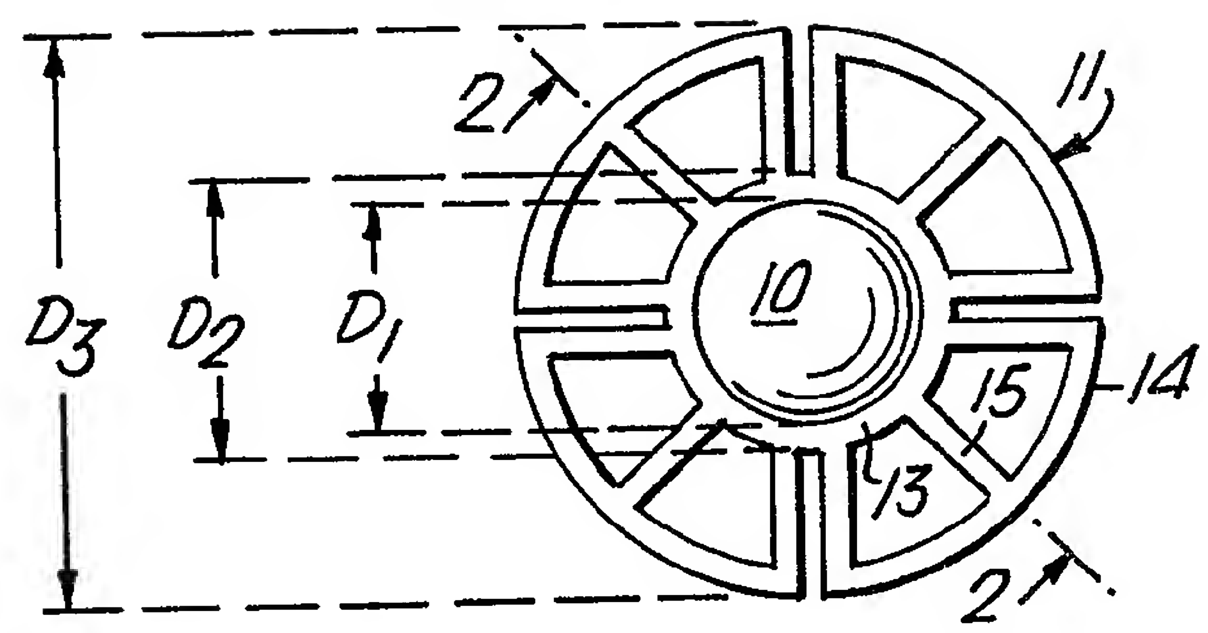



Fig. 2.


Fig. 3.

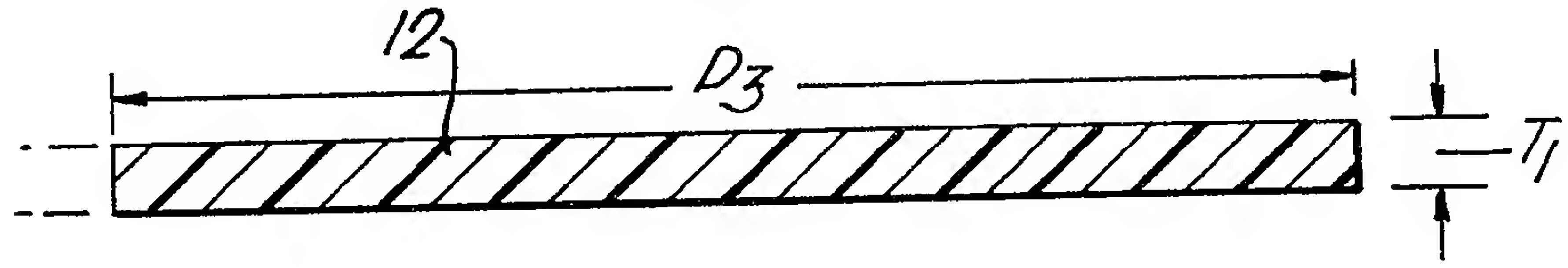



Fig. 4.

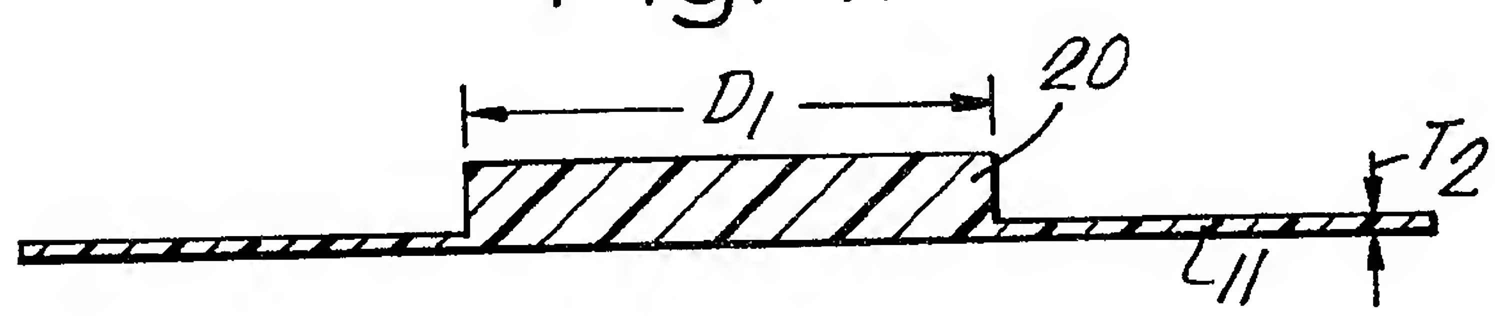



Fig. 4A.

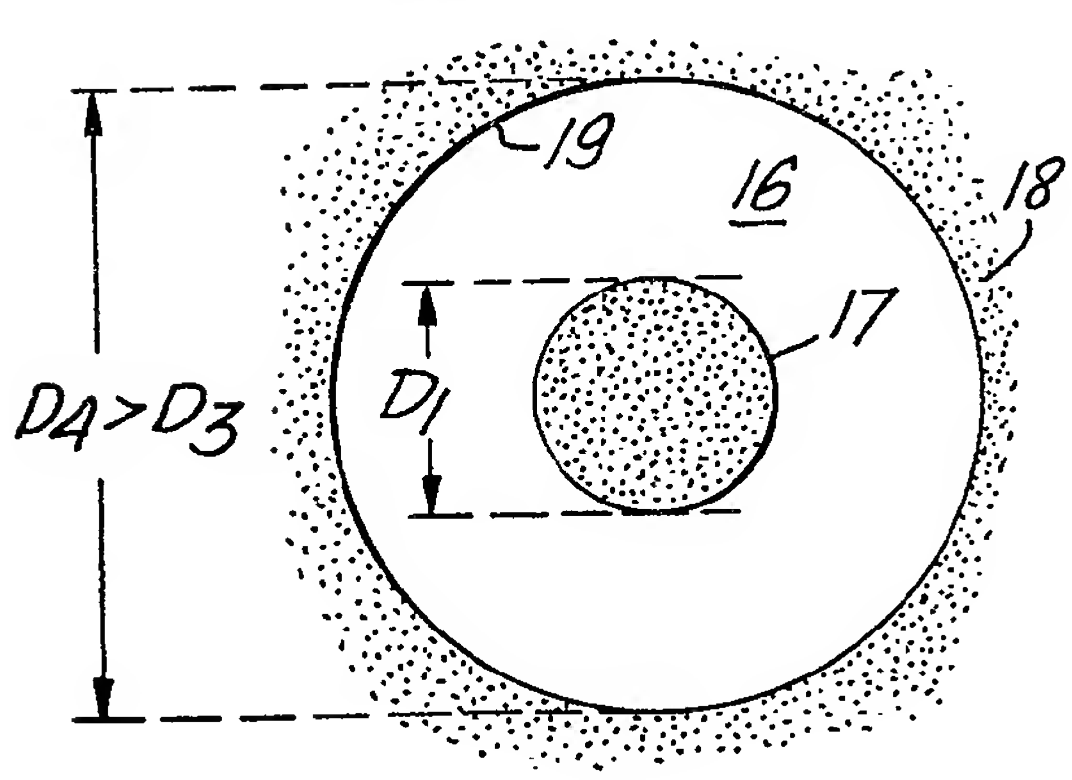



Fig. 4B.

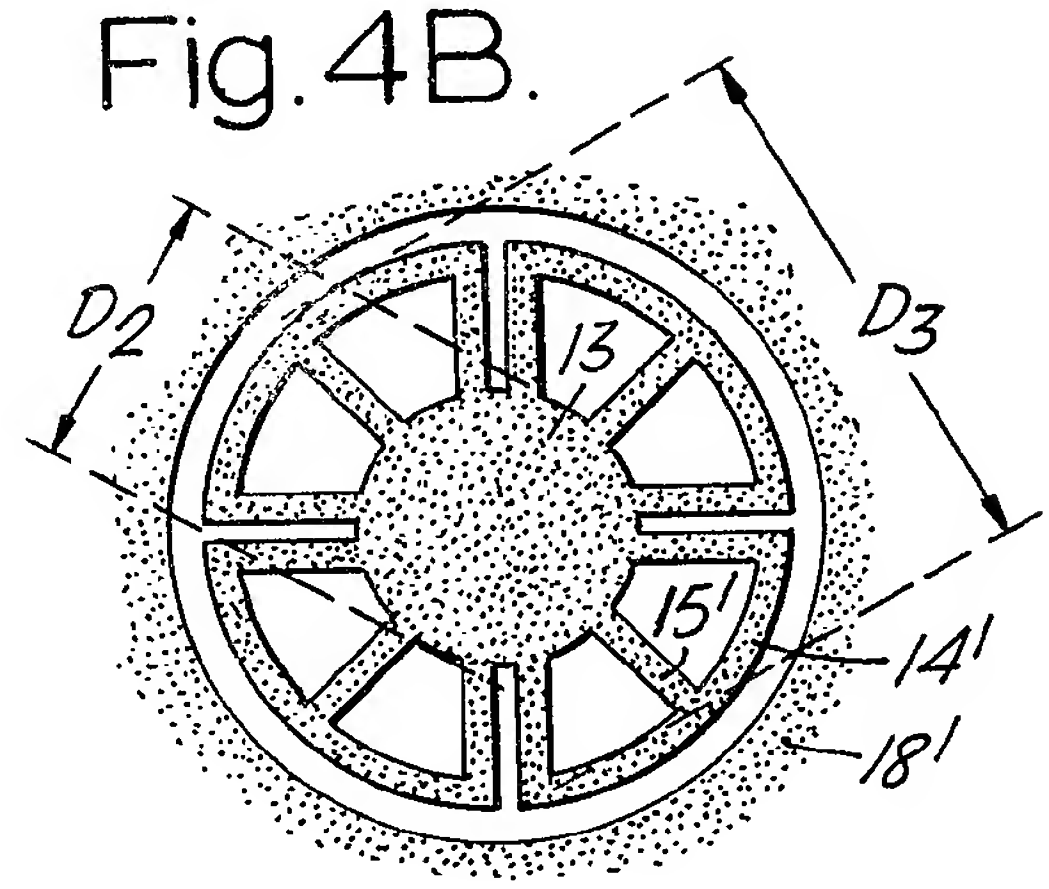


Fig. 5.

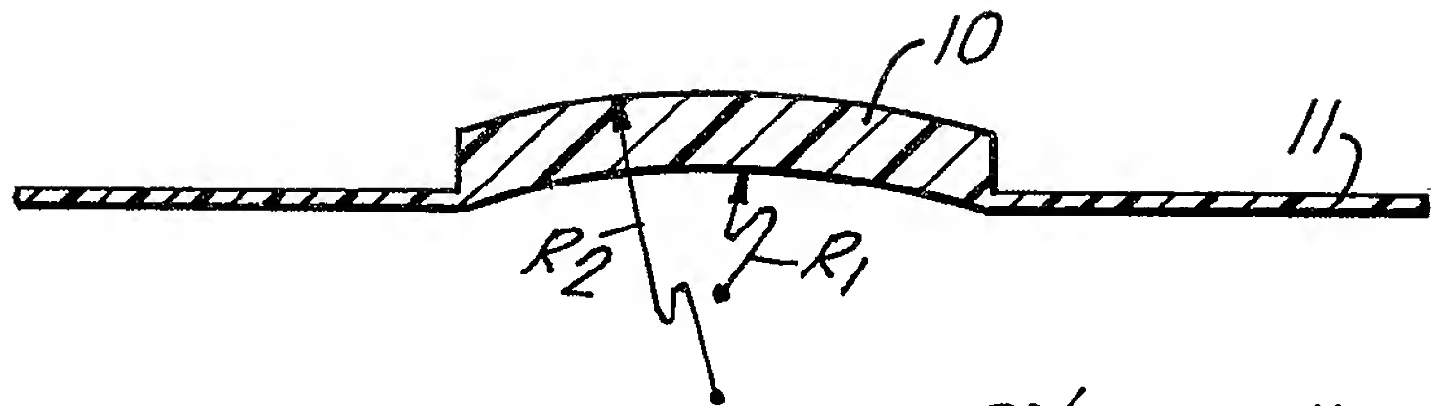



Fig. 6.

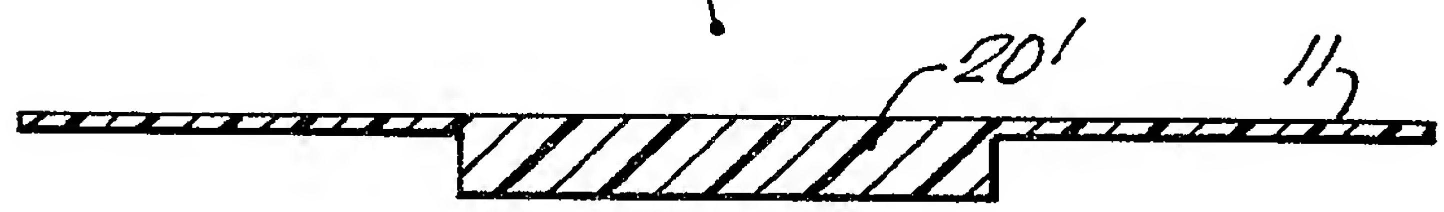



Fig. 7.


Fig. 8.

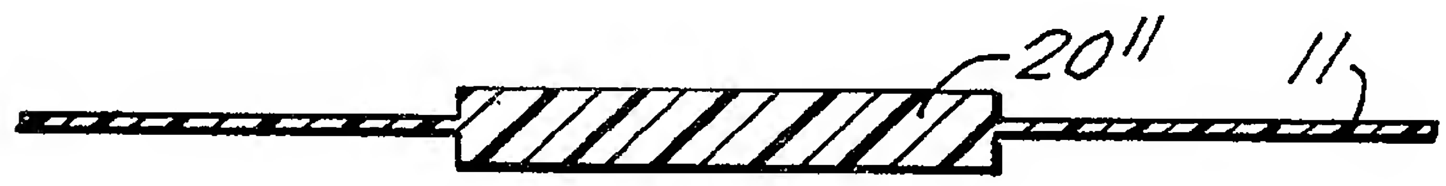



Fig. 9.


Fig. 10.

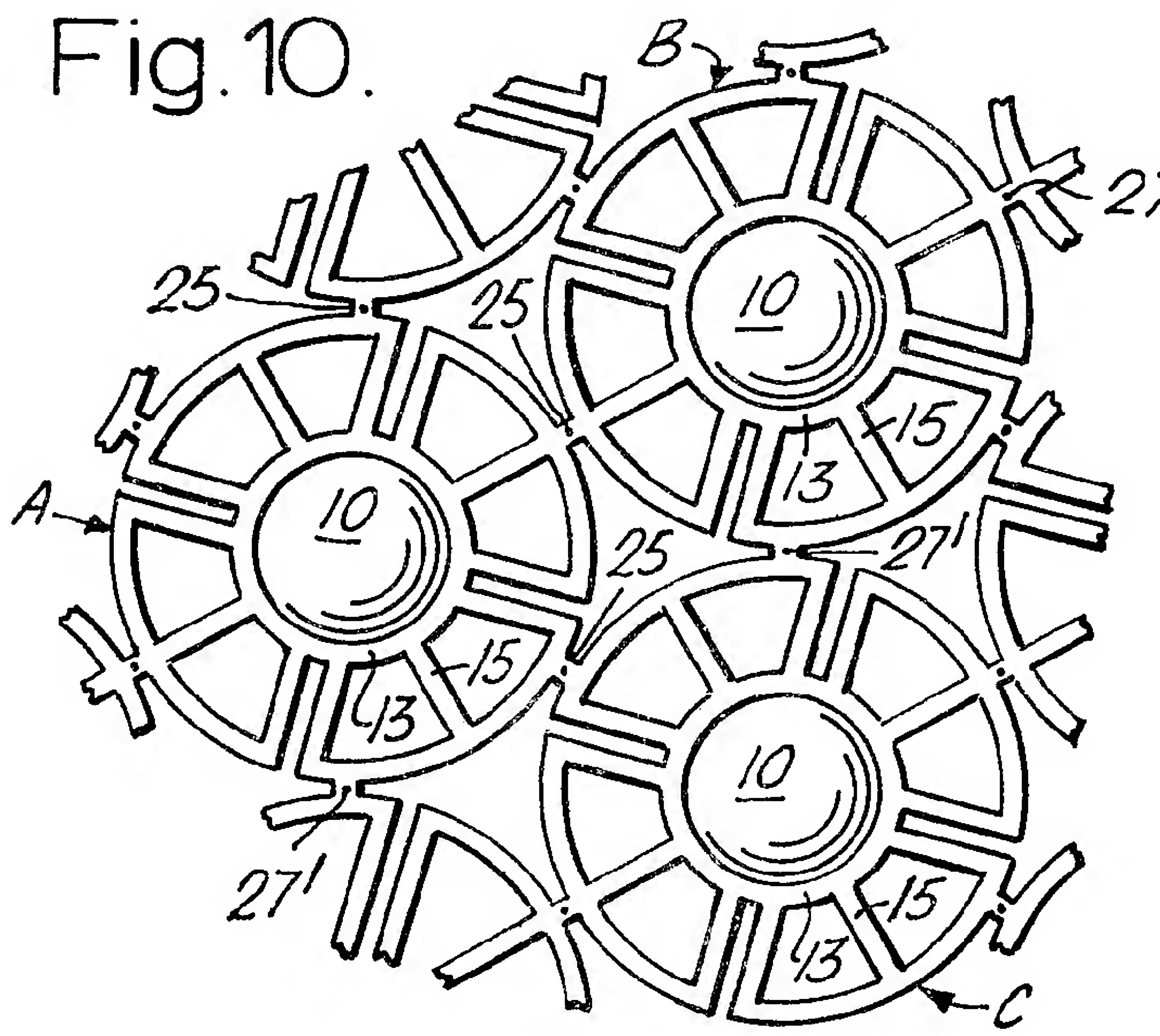


Fig.11.

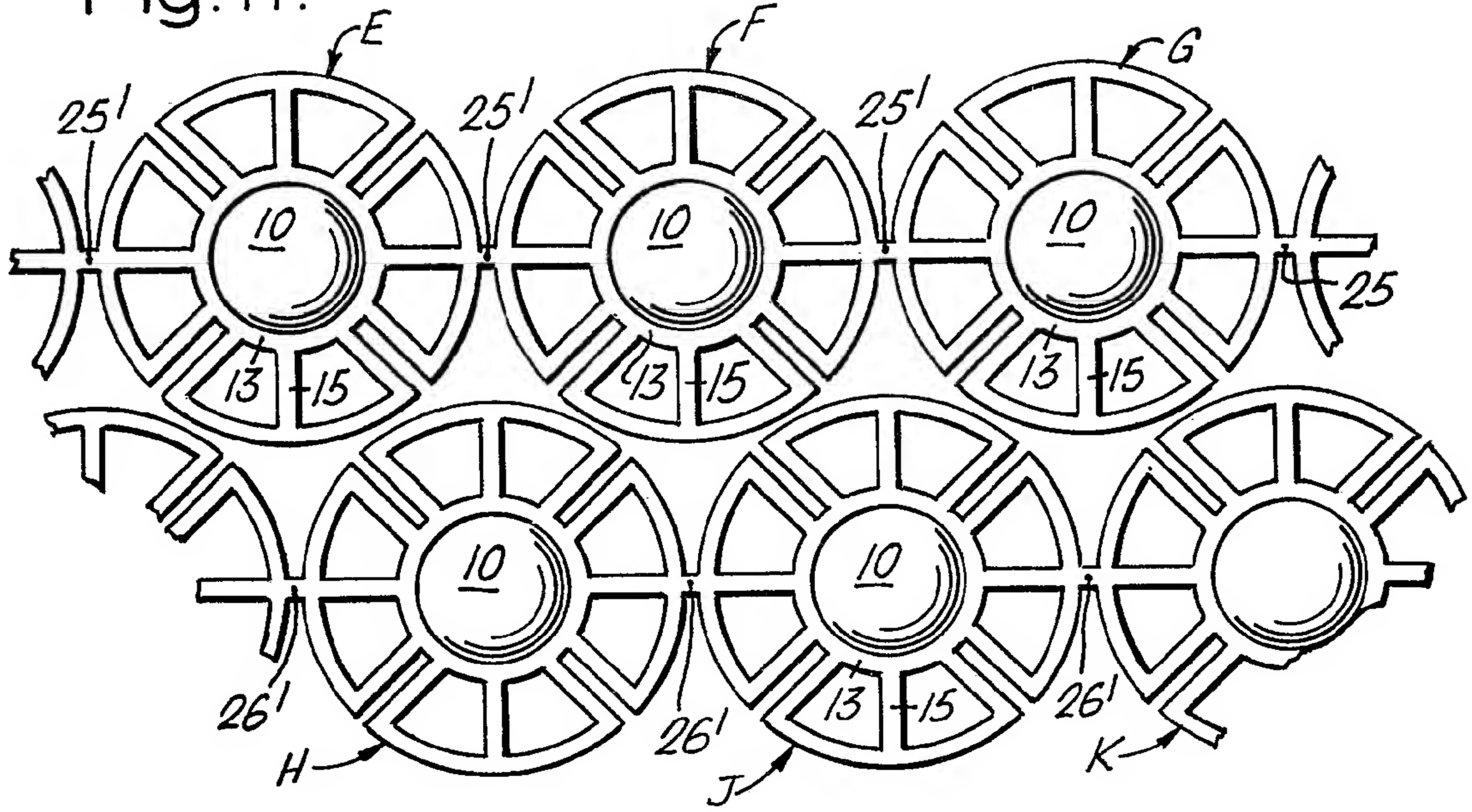



Fig.12.

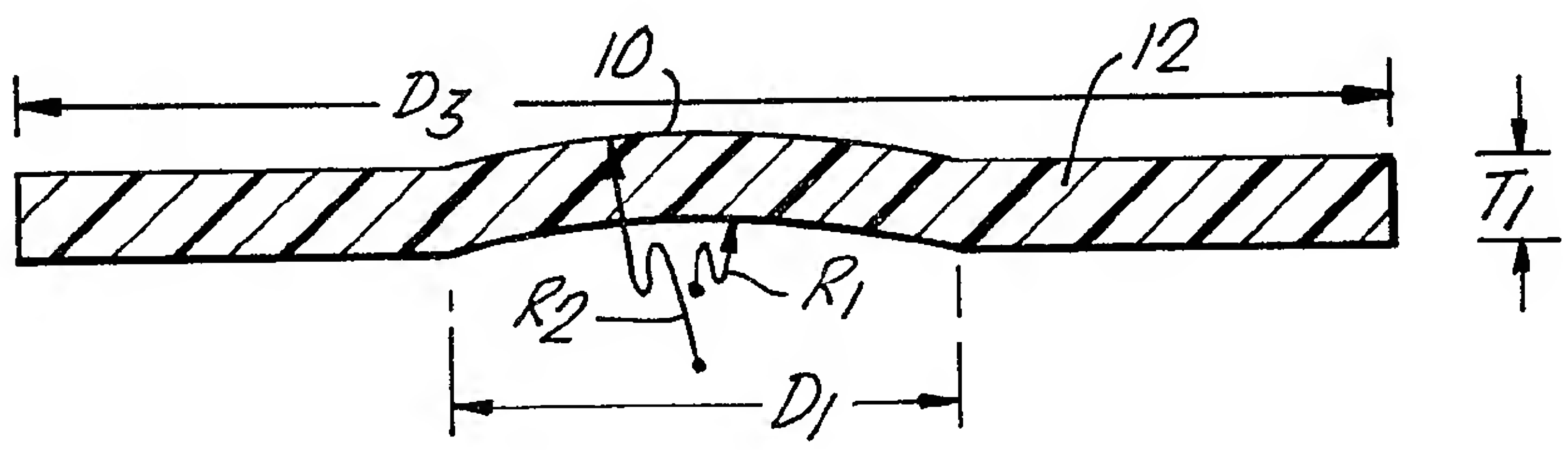



Fig.13.

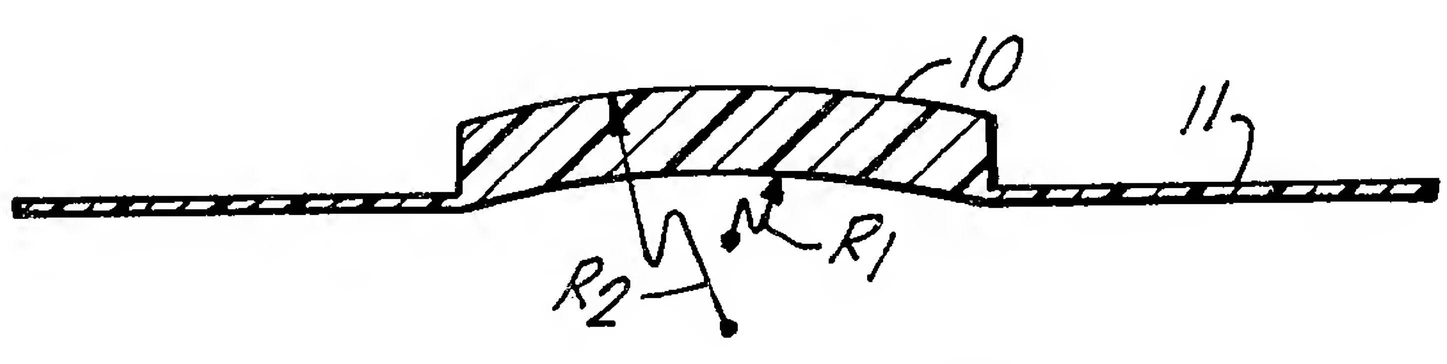



Fig.14.

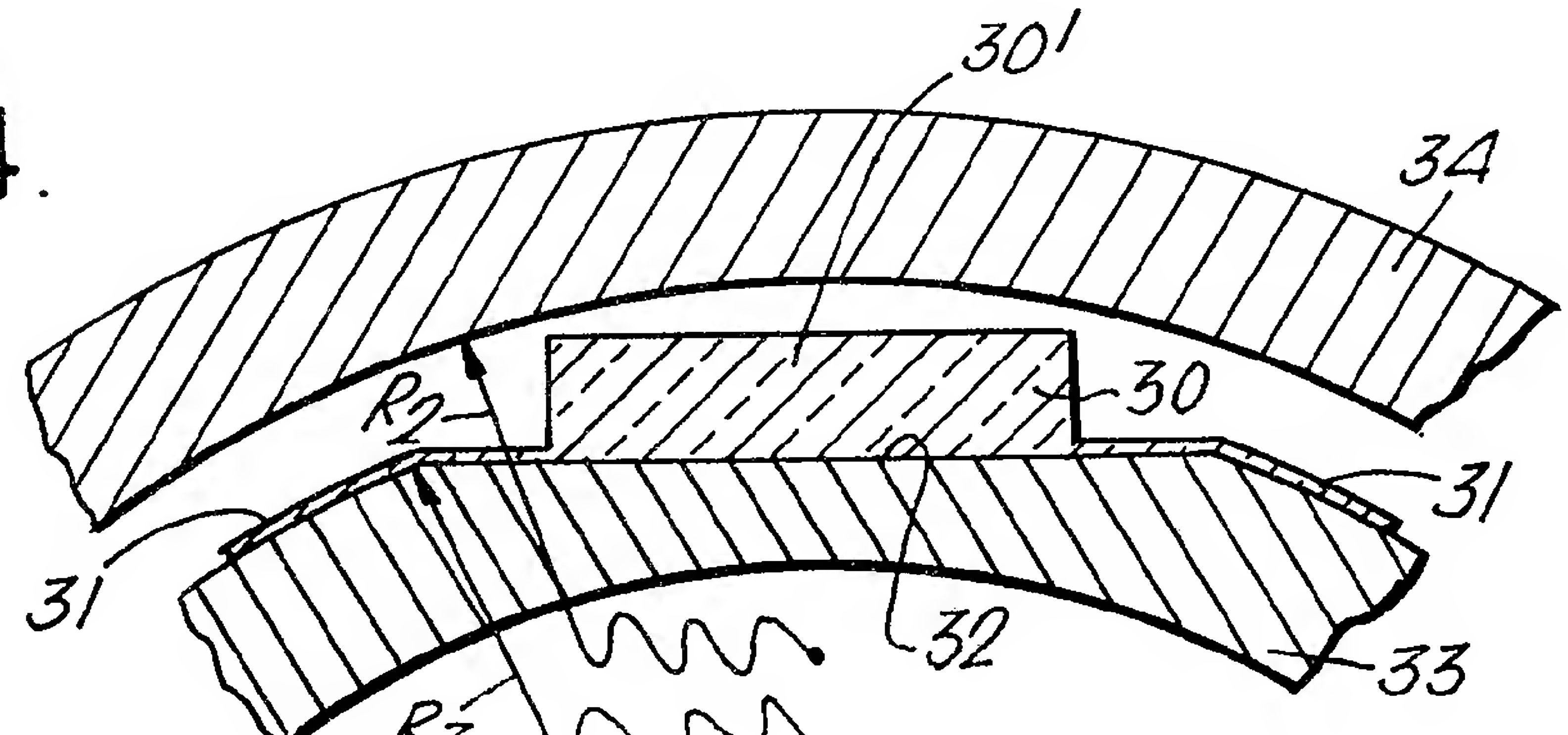


Fig.15

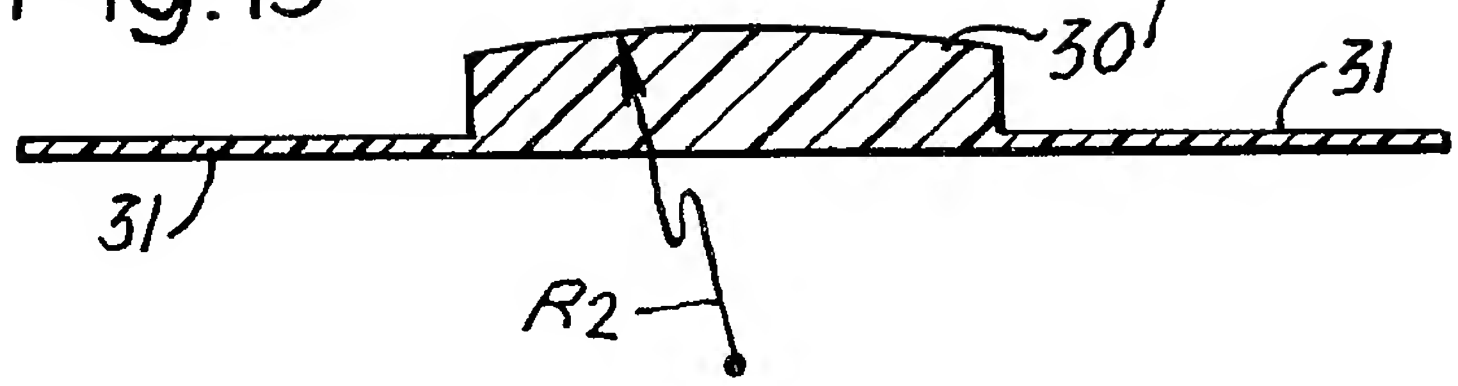



Fig.16.

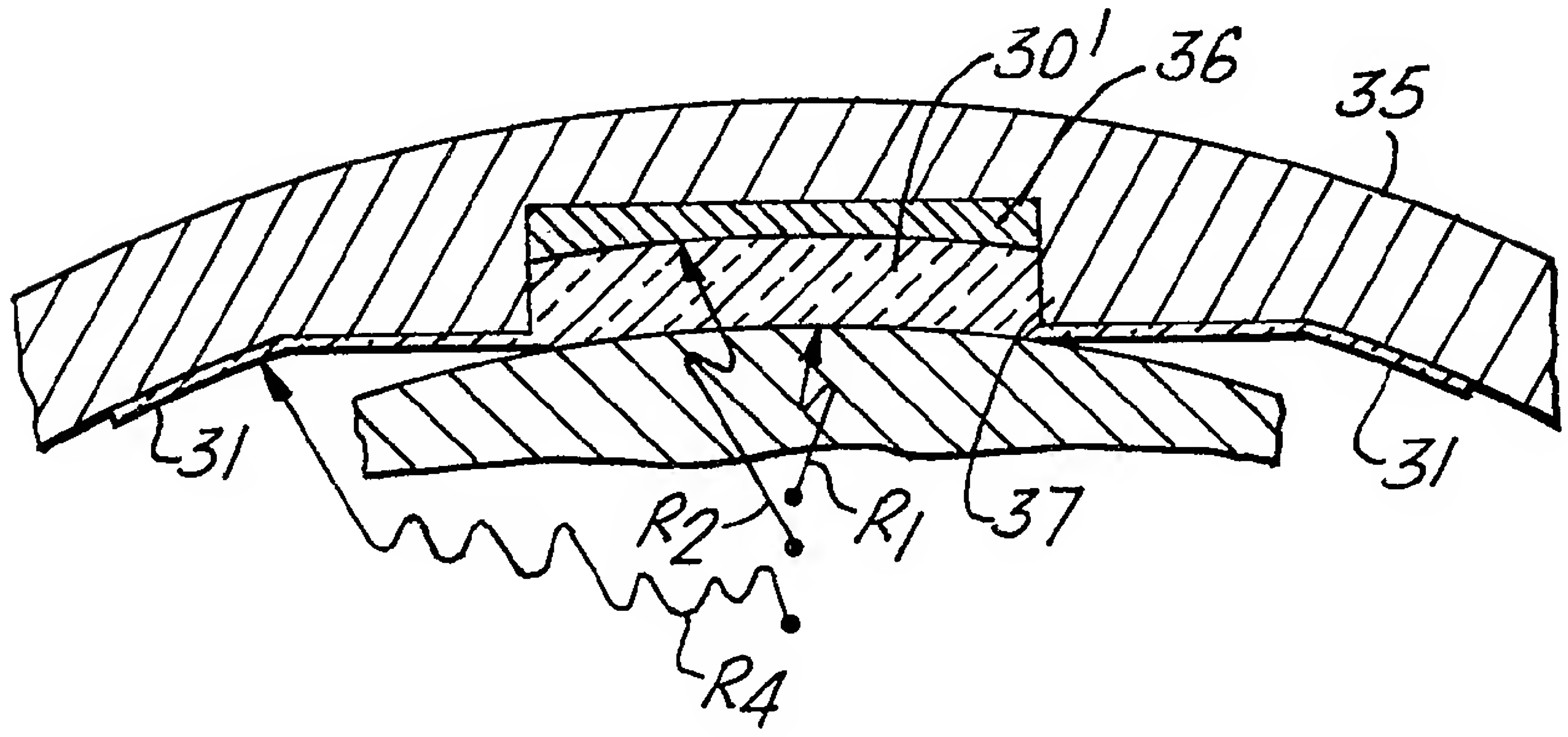



Fig.17.

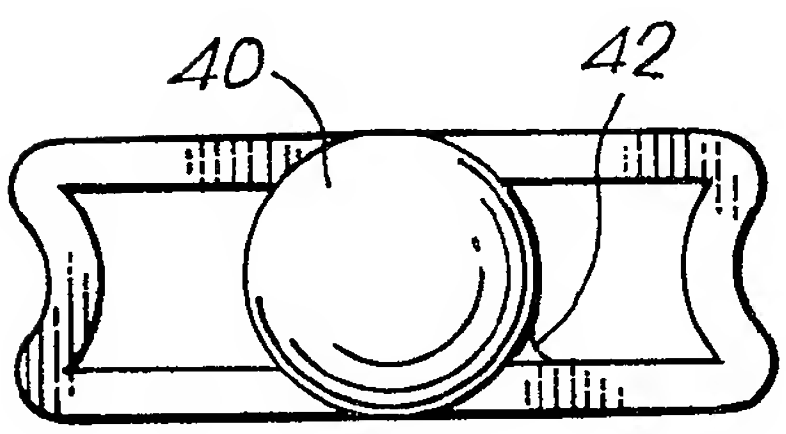



Fig.18.

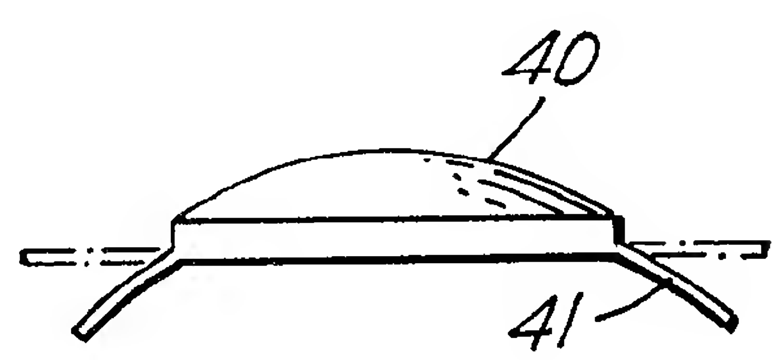



Fig. 19.

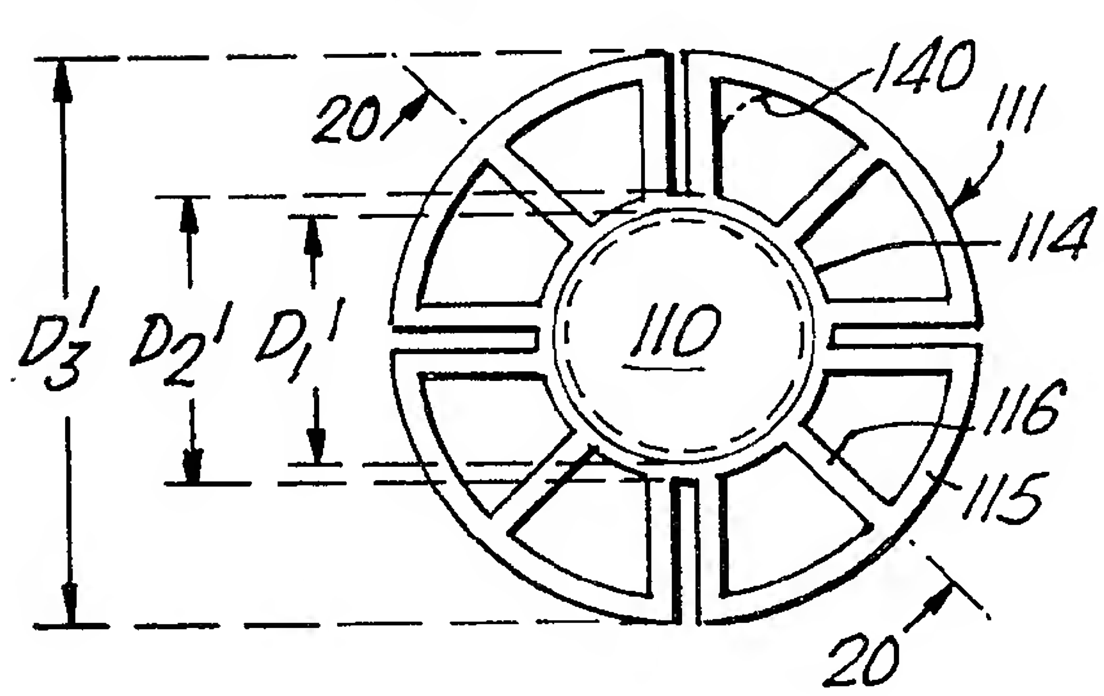



Fig.20.

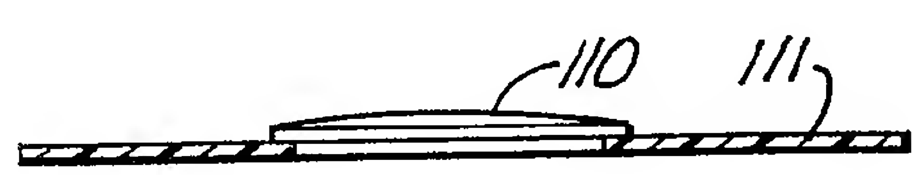


Fig.21.

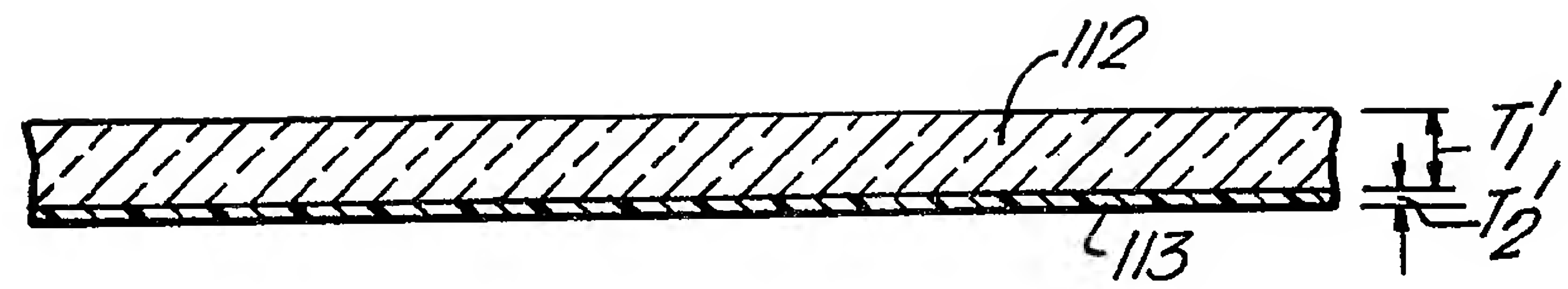



Fig.22.

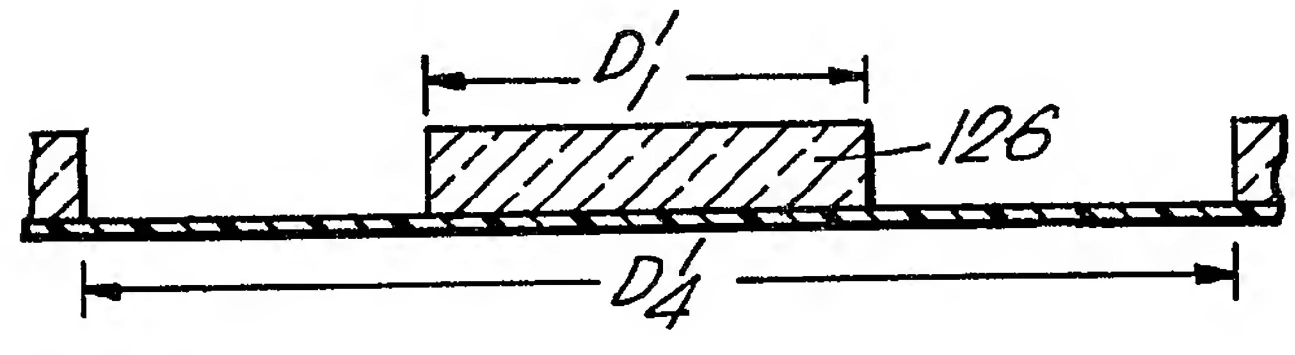



Fig.23.

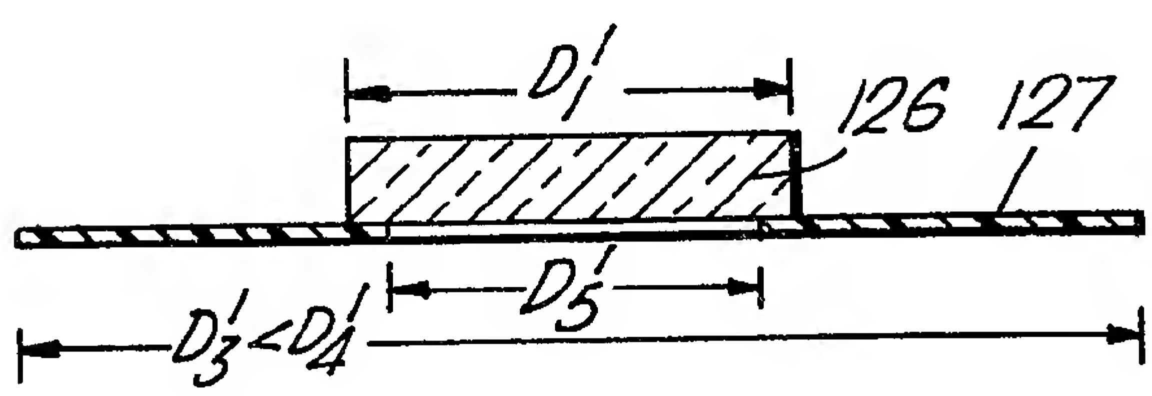



Fig.21A.

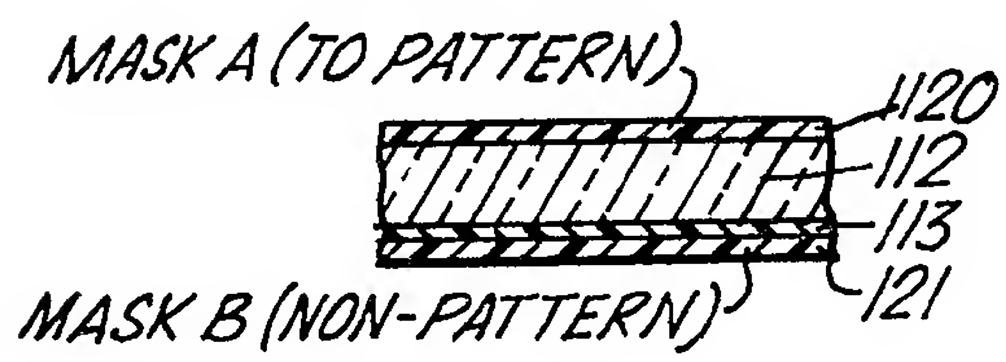



Fig.21A.

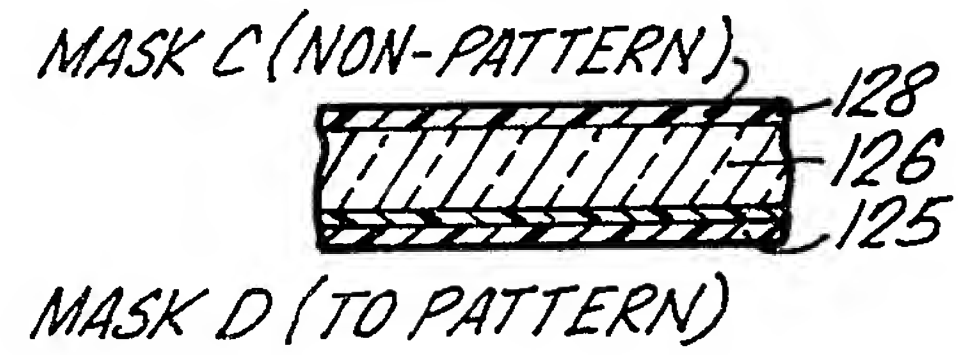



Fig.21B.

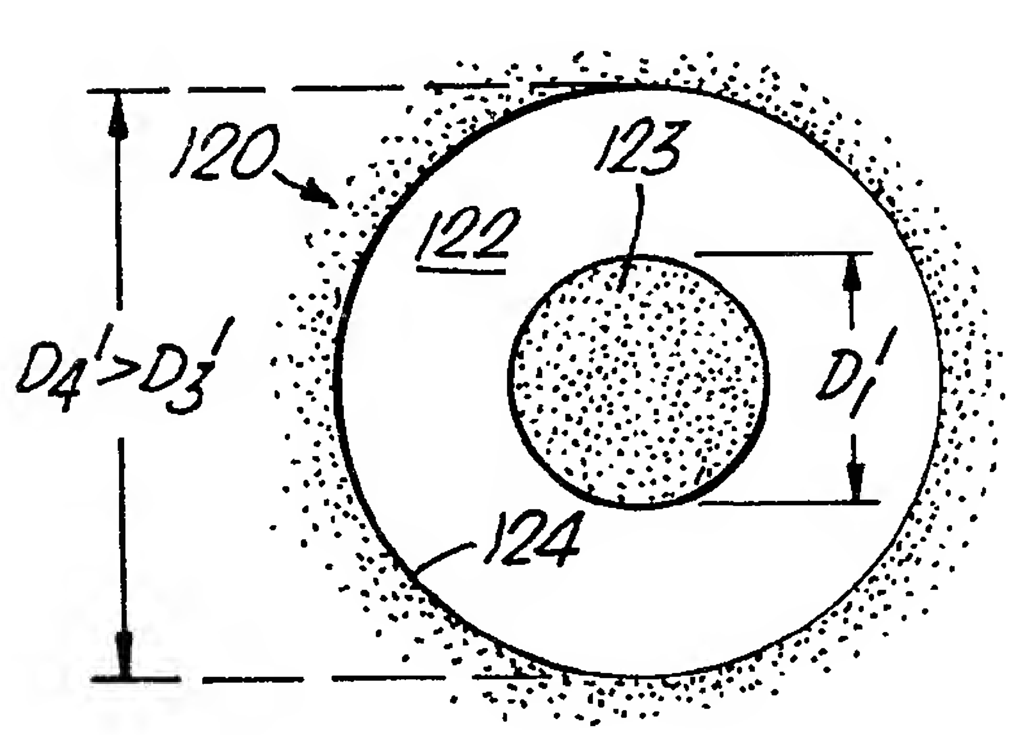



Fig.22B.

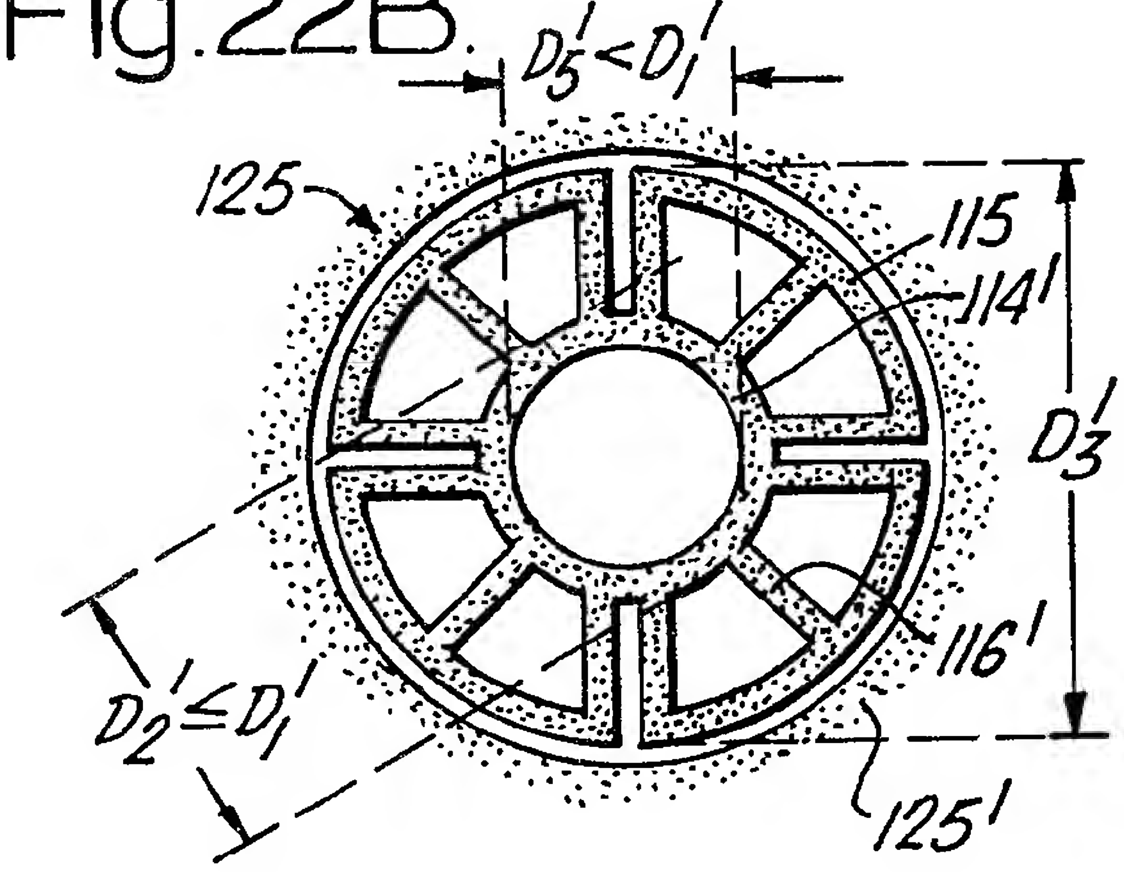


Fig.24.


Fig.25.

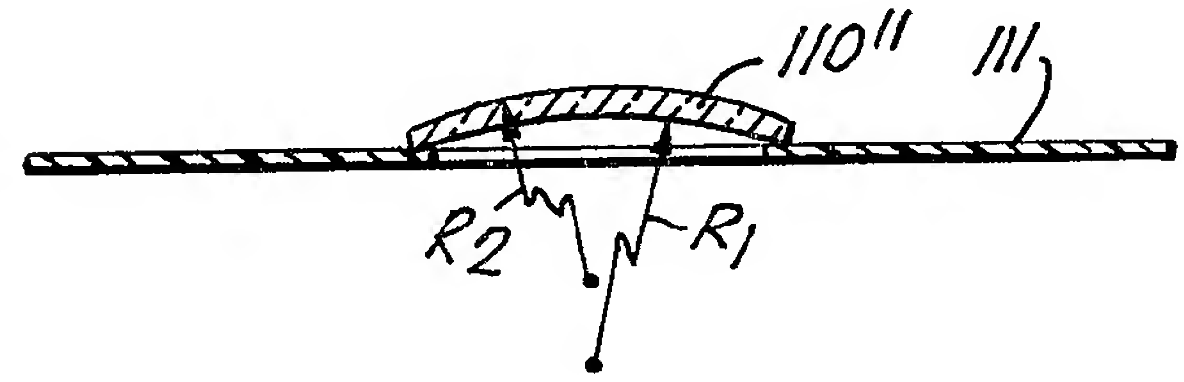



Fig.26.

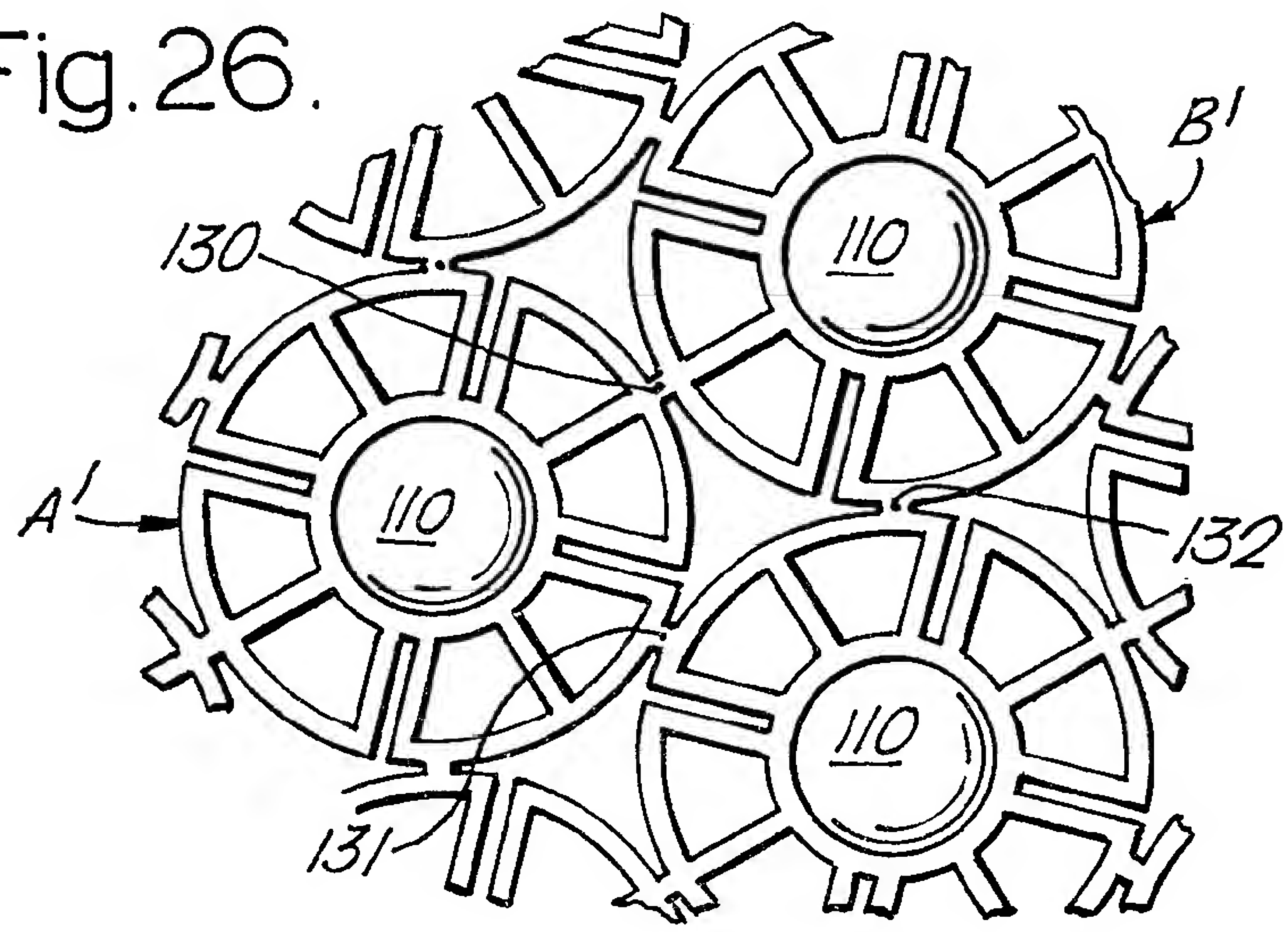
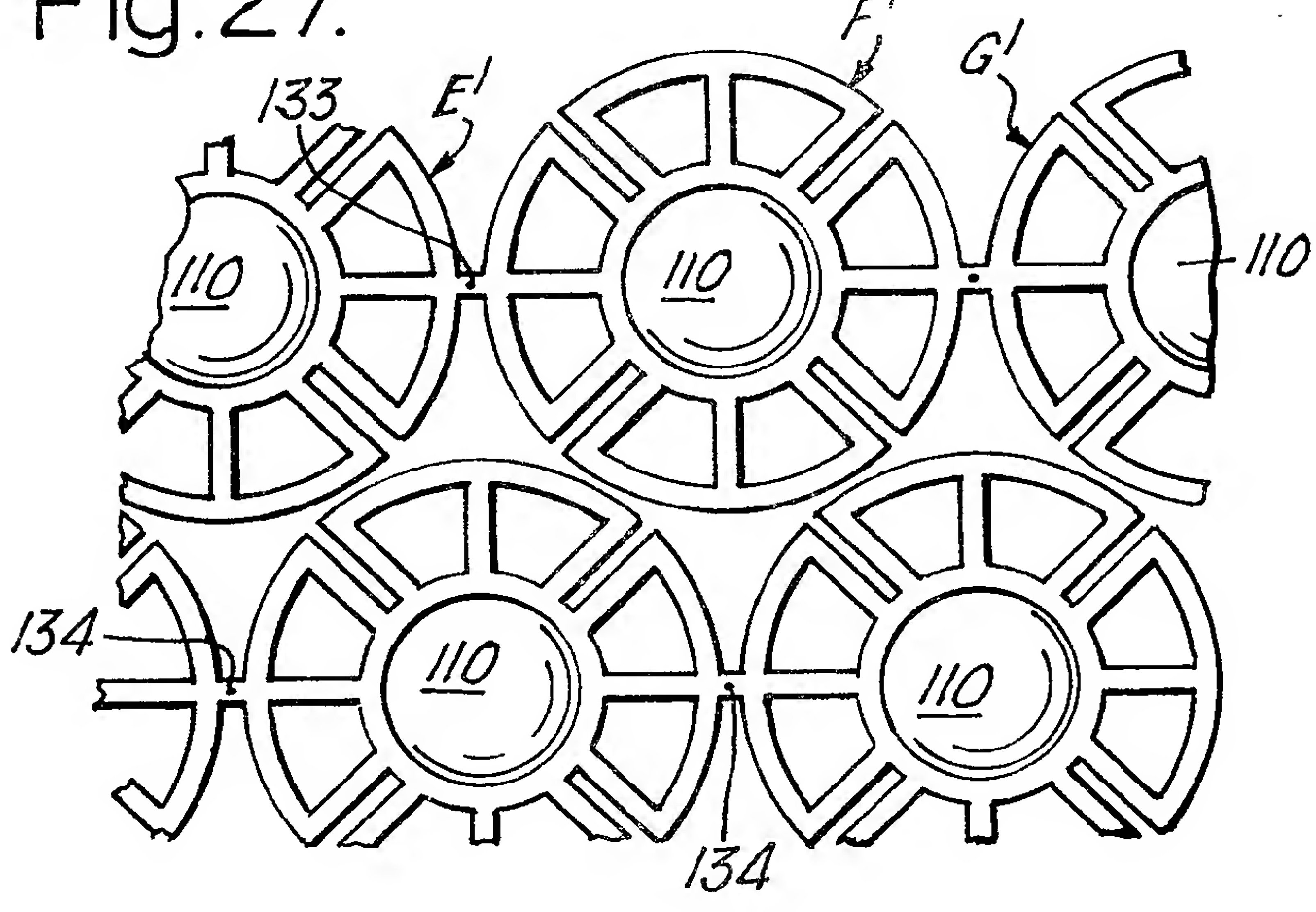



Fig.27.



SPECIFICATION

**Intraocular and extraocular lens construction and method of making the same**

This invention relates to lens and haptic structures having application as intraocular lens implants, or as extraocular devics for contact application to the cornea, for wear in place of spectacles.

As intraocular devices, such structures and methods of making the same are illustratively treated in my U.S. Patent No 4 080 709, and as extraocular devices, such structures are illustratively treated in my copending application, Serial No 124 941, filed february 26, 1980.

Design philosphy behind intraocular and extraocular devices of the character indicated holds that the lens elements shall be an optically finished unitary part, and that associated haptic structure shall be a separate thin flexible part or parts devised and assembled for central support of the lens element and for suitably compatible stabilised referencing engagement with adjacent body features.

There is another category of intraocular lens, exemplified by Choyce, et al., U.S. Patent No 4 087 866, wherein lens and haptic structure are the integral product of plastic-molding. But such products do not lend themselves to fabrication with glass, nor to known glass-lens finishing techniques. Moreover, injection-molded plastic materials are inherently incapable of providing the optical quality and uniformity that is available from glass and from certain plastic materials which are available in flat-sheet form.

My copending U.S. application, Serial No. 288217, filed July 29, 1981, is concerned with structures and methods, involving intraocular and extraocular devices of the character indicated, wherein the starting material is a single flat sheet of glass or suitable plastic, and the present application is concerned with similar devices wherein the starting material is a composite laminate of different materials.

It is an object to provide improved integrally formed lens and haptic structures of the character indicated.

One specific object is to provide methods of manufacture of such structures which are inherently applicable to fabrication from glass or from a plastic, as the starting and the only material of the ultimate product.

Another specific object is to provide such structures from a starting composite laminate wherein one lamination is optimised for its optical properties and another lamination is optimised for supporting haptic purposes.

A further specific object is to meet the above specific objects with structures and techniques which utilise flat sheet material as the starting and only material of the ultimate product.

The invention achieves these objects and certain further features by employing suitably coordinated masking and etching steps to determine the peripheral contour of the ultimate central lens as well as the thickness and fenestration detail of the ultimate thin flexible haptic formations which are integral with and extend radially outward of the lens blank. In one illustrative embodiment, the starting material is a single sheet flat stock, of thickness to provide for the overall ultimate axial extent of the lens; in another illustrative embodiment, the lens and haptic formations are from laminated starting materials the haptic formations remaining effectively integral with and extending radially outward of the lens blank. In all cases, the starting material is flat composite laminated-sheet stock, of thickness to provide for the overall ultimate axial extent of the lens. Lens-surface curvature may be developed prior to but is preferably developed after haptic formation. The masking and fenestration detail are provided via photoetch techniques and are applicable to mass production of plural duplicates of the identical lens-and-haptic structures from a single composite laminated sheet, through formative operations performed concurrently and in common on all structures of a given sheet.

Illustrative structures and techniques of the invention will be described in detail in conjunction with the accompanying drawings, in which:

*Figure 1* is a plan view of an illustrative first embodiment, being a single-piece integrally formed lens and haptic construction of the invention;

*Figure 2* is a sectional view, taken at 2–2 in Fig. 1;

*Figure 3* is an enlarged schematic sectional representation of sheet starting material, for the aspect depicted in Fig. 2, i.e., what begins as shown in Fig. 3 ultimately becomes what is shown in Fig. 2;

*Figure 4* is a diagram similar to Fig. 3, to show the result of an intermediate step in proceeding from the material of Fig. 3 to the product of Fig. 2;

*Figures 4A and 4B* are diagrammatic representations of different masks used to create the intermediate stage of Fig. 4;

*Figure 5* is a view similar to Fig. 4, to illustrate a finishing step, for the product of Figs. 1 and 2;

*Figures 6 and 7* are views similar and respectively corresponding to Figs. 4 and 5, to illustrate a modification;

*Figures 8 and 9* are views similar and respectively corresponding to Figs. 6 and 7, to illustrate a further modification;

*Figures 10 and 11* are similar fragmentary plan views of two alternative multiple-structure layouts on a single sheet of starting material, for mass-production purposes.

*Figures 12 and 13* are sectional views to

the scale of Figs. 3, 4 and 5, to illustrate a modified technique;

*Figures 14 and 15* are sectional views, to the scale of Figs. 4 and 5, to illustrate successive finishing steps for simultaneously finishing the convex surface of each of a plurality of lens elements of optical glass;

*Figure 16* is a diagram similar to Fig. 14, to show a set-up for simultaneously finishing the concave surface of each of a plurality of lens elements of optical glass;

*Figure 17* is a plan view of a modified integral lens and haptic construction;

*Figure 18* is a view in side elevation of a construction as in Fig. 17;

*Figure 19* is a plan view of a single-piece effectively integrally formed lens and haptic construction of the invention;

*Figure 20* is an enlarged sectional view, taken at 20–20 in Fig. 19;

*Figure 21* is a further-enlarged schematic sectional representation of a sheet of composite laminated starting material, for the aspect depicted in Fig. 20, ie., what begins as shown in Fig. 21 ultimately becomes what is shown in Fig. 20;

*Figures 22 and 23* are diagrams similar to Fig. 21 to show the result of different intermediate steps in proceeding from the material of Fig. 21 to the product of Fig. 20;

*Figures 21A and 22A* are sectional views, and

*Figs. 21B and 22B* are diagrammatic representations to show use of different masks to create the respective intermediate stages of Figs. 22 and 23;

*Figures 24 and 25* are views similar to Figs. 22 and 23, to illustrate two different finishing steps for the product of Figs. 19 and 20; and

*Figures 26 and 27* are similar fragmentary plan views of two alternative multiple-structure layouts on a single sheet of starting material, for mass-production purposes.

In the form of Figs. 1 and 2, the invention is shown in application to an extraocular or contact-lens assembly, strongly resembling multiple-component structure as disclosed in my said copending application, Serial No 124 941, but in reality comprising a central lens 10 and haptic structure 11 which are integral with each other, being the product of selectively etched reduction from starting material in the form of flat sheet stock 12, of thickness $T_1$, as shown in Fig. 3. As will later appear, the sheet stock 12 may be suitable plastic or glass, and inert to body fluids. For convenience, dimensional symbols have been applied to identify: lens diameter at $D_1$, which may be in the range of 6 to 9 mm; an inner circumferential haptic band or ledge 13, which is preferably at least 0.25 mm wide, to account for its outer diameter $D_2$ in the range of 6.5 to 9.5 mm; and haptic outer diameter $D_3$ which may be in the range up to 20 mm, and thus in excess of the 12 to 14 mm diameter of the iris of an eye. It will be understood that haptic 11 may be characterised by very substantial fenestration, meaning that the structure is primarily "open", for normal air or "breathing" exposure of the surface of the cornea to which it is applied. Such substantial fenestration is shown and described in said copending application Serial No 124 941, and is therefore not repeated here. It suffices to note that the detail of fenestration and the varieties of haptic configuration of said copending application are achievable for the techniques and structures to be described herein; therefore, such detail is not here repeated. It is also to be noted that the detail of haptic configuration and size, for intraocular-lens application, including lens size and power appropriate to intraocular use, may be achieved with the invention, so that dimensions and shapes given herein for the extraocular situation are to be regarded as merely illustrative and not limiting.

It suffices here to describe the haptic 11 as comprising four arcuate feet 14, connected to each other and to lens element 10 only via integral radial legs 15 to ledge 13. Lens thickness $T_1$ is generally in the range of 0.001 to 0.007 inch, for extraocular applications, and in the range of 0.002 to 0.020 for intraocular applications; and haptic thickness $T_2$ (Fig. 4) is in the order of 0.001 to 0.003 inch for both applications.

To proceed from the sheet 12 of Fig. 3 to the intermediate stage of Fig. 4, I utilise mask and photoetch techniques which are illustratively described in my Patent No 4 080 709 and which therefore need not be repeated here. It suffices to indicate that for present purposes, a mask as in Fig. 4A is used for the chemical or other etching of the upper surface of sheet 12, and that a different mask as in Fig. 4B is used for such etching of the lower surface of sheet 12. These two different etchings may proceed concurrently, but I prefer to perform each operation separately, thereby achieving full control of the particular depth of erosion desired from each side of sheet 12.

More specifically, the mask of Fig. 4A may be a precise photographic reduction from a master drawing, the reduction being to expose a photosensitive coating of the upper surface of sheet 12, the exposed coating being thereafter developed to leave a deposited opaque masking pattern on the sheet. Since it is my preference to first etch from one side and then from the other, I fully expose the photosensitive coating on the lower surface of sheet 12, so that upon development, the lower surface is entirely opaque and is thus incapable of permitting an etch from the lower side. With the thus-masked sheet then exposed to an etching environment, only the areas not opaquely masked will be etched, and this first etching is timed for penetration to the depth

$T_1-T_2$, thus leaving only haptic thickness $T_2$ in the etched region. As seen in Fig. 4A, this first mask is characterised for etching exposure of the circular annulus 16, defined internally by a lens-size opaque circular area 17 of diameter $D_1$ and on the outside by a circumferentially enveloping opaque area 18. The outer opaque area 18 has a circular inner edge 19 of diameter $D_4$ slightly greater than ultimate haptic diameter $D_3$.

Having etched through the mask of Fig. 4A to the depth $T_1$-$T_2$, all maskings are stripped and the specimen recoated with photosensitive material. The mask pattern of Fig. 4B is then exposed and developed on the underside of the specimen, in precise concentric relation with the Fig. 4A exposure and etching, while the upper surfaces of the central lens-blank region 20 and surrounding annular haptic area 11 are totally exposed and developed to render etching exposure only through the Fig. 4B mask on the lower surface of the specimen. This second etching is allowed to proceed fully through the ultimate haptic thickness $T_2$, at which time the intermediate product of Fig. 4 becomes severed from surrounding original sheet material. It is, of course, possible then to strip maskings from the specimen and to proceed thence with lens-finishing. However, it is my preference that the mask of Fig. 4B be formed with at least one later-severable tie-forming opaque connection between the fenestration-defining inner portion (within diameter $D_3$) and the surrounding opaque pattern 18', corresponding to surrounding mask material at 18 in Fig. 4A.

The inner pattern of the mask of Fig. 4B, i.e., within the inner circular edge of surrounding opaque material 18', will be seen to have the haptic-fenestration detail described in connection with Fig. 1, and therefore in Fig. 4B corresponding inner opaque parts of this mask are given in Fig. 1 reference numbers, with primed notation. However, in the mask of Fig. 4B, the full area 13' within the outer confines of ledge 13, i.e., within the circle of diameter $D_2$ is opaque, to avoid etching the lens blank region 20.

Having performed the second etch to the pattern of Fig. 4B, all mask deposits are stripped from the partially completed specimen, to permit lens-finishing. In the individually separated specimen situation, each item must be separately handled, but in the edge-interconnected situation, the individual specimens may be more readily handled by mass lens-finishing techniques. One pattern of edge-interconnected specimens is illustrated in Fig. 10, wherein each partially completed specimen (per Fig. 4) is in nested adjacency to and interconnected with six surrounding like specimens; in the fragmentary showing of Fig. 10, three thus-nested partially completed specimens A-B-C are connected, as by a severable tie 25 between specimens A and B, by a severable tie 26 between specimens A and C, and by a severable tie 27 between specimens B and C.

Fig. 11 is a diagram smaller to Fig. 10, but showing a different pattern of severable interconnection of partially completed specimens, also lending itself to mass-production handling in lens-finishing phases of production, as will later become more clear. In Fig. 11, the pattern of severable interconnection is on discrete parallel alignments of connection. For example, the partially completed specimens E-F-G of one such alignment are severably interconnected at 25' to each other, and the partially completed specimens H-J-K of the next adjacent such alignment are severably interconnected (at 26') but are not connected to the specimens of alignment A-B-C or to those of any other alignment. In other words, the arrangement of Fig. 11 permits automated handling of linear arrays of severably connected specimens.

Returning now to the matter of lens-finishing, and taking the case of having performed etching steps on a starting sheet of suitable plastic, the partially completed specimen of Fig. 4 is first accurately positioned in a forming die. Then, the lens shape which may involve an inner concave surface of radius $R_1$ and an outer convex surface of different radius $R_2$, is established by plastic deformation under elevated compressional pressure within the die, resulting in a finished product, as shown in Fig. 5. In this particular finished product, it will be noted that the convex anterior surface of lens 10 is offset from the ledge 13 of integral haptic 11 connection, and that the posterior surface of lens 10 is effectively flush with the haptic.

Figs. 6 and 7 illustrate a modification wheren the etching to form the haptic 11 uses masks as in Figs. 4A and 4B in the reverse orientation from that described in Fig. 4, in order to produce haptic connection with the lens blank 20' at the anterior region, and at axial offset from the posterior surface of the lens blank. In other words, the first or step-edging procedure to the mask pattern of Fig. 4A may be developed in reference to the lower (potentially posterior) surface of the starting sheet 12, while the haptic-detail etching attributable to the mask pattern of Fig. 4B may be developed in reference to the upper (potentially anterior) surface of sheet 12. Lens curvature may be developed as previously described, resulting in Fig. 7 in a plane anterior surface of the lens 10 and a concave posterior surface. It goes without saying that if permanent curvature is desired in either of the lens and haptic configurations of Figs. 5 and 7, such haptic curvatures may be the product of the same compressional die procedure as induces lens curvatures.

Figs. 8 and 9 illustrate that described

masks and etching may also be used to produce an integral lens and haptic configuration wherein the haptic 11 integrally joins the lens-blank region 20'' at axial offset from both the anterior and the posterior surfaces of the lens. To produce this configuration, the first etching step is performed on a blank sheet 12 which has had mask deposits to the pattern of Fig. 4A, applied in axial register to both sides of the sheet. Etching is timed to achieve haptic thickness $T_2$, but since etching proceed simultaneously against identical Fig. 4A masks on both sides of sheet 12, the etch time will be one half that required for first etching in the Fig. 4 and Fig. 6 situations. Second etching, to the pattern of Fig. 4B may be as described for either of the Fig. 4 or Fig. 6 situations, as will be understood.

Thus far, all procedures have involved mask and etch techniques first, followed thereafter by lens-finishing steps. But Fig. 12 illustrates that this is not necessarily to be considered a limiting sequence. In Fig. 1, the lens-defining steps are first performed on the starting sheet 12, the particular lens shown being recognisable as that of Fig. 5. Therafter, it will be understood that any of the various mask-and-etch sequences described for Figs. 4, 6 and 8 may be used, depending on the desired ultimate axial location of integral haptic connection to the lens 10. For illustration, Fig. 13 shows the product configuration of Fig. 5 resulting from mask-and-etch sequences of Fig. 4, applied to the pre-formed lens 10 of Fig. 12.

Also thus far, all procedures and configurations have been described with a tacit assumption that the starting material is a plastic sheet 12. But this need not be the case, in that the sheet 12 may be of optical-quality glass, with etching techniques performed as appropriate for glass, in the context of masks (e.g., to Fig. 4A and 4B patterns) of nature appropriate to the etching technique. Nor is compressional-die deformation of the sheet material 12 to be limited to plastics, in that upon application of heat to induce softening, the pressed deformation of glass-lens-blank regions of integral lens-and-haptic structures consisting entirely of the same piece of glass are feasible.

It is, however, my preference that recognised optical-finishing techniques be employed in the finishing of integral lens-and-haptic configurations which are made of glass. And Figs. 14, 15 and 16 illustrate this preference.

In Fig. 14, a partially completed all-glass specimen comprises a central lens blank 30 with integral haptic features 31 which are sufficiently thin to be axially compliant. The flat blank region 30 is mounted to a suitable flat platform location 32 of a conventional generally truncated spherical multiple-blank support 33, being removably affixed thereto by wax embedment in accordance with accepted practice, and wax being also used to removably retain the flexible haptic portions 31 in conformance to curved surfaces of support 33, adjacent the platform locations 32. The curvature of radius $R_3$ to which haptic features 31 are thus temporarily conformed is less than or at least relieved from the locus of ultimate convex grinding curvature $R_2$ to which the anterior surface of blank 30 is to be ground. For such grinding, a master grinding member 34 having a concave master-grind curvature of radius $R_2$ is shown poised at offset from blank 30 and its support 33, in readiness to commence conventional grinding of the convex anterior lens surface, to radius $R_2$.

It should be noted that support 33 may include flat platforms 32 at spacings and alignments appropriate to the multiple mounting of severably connected partially completed all-glass specimens, for example, a longitudinally connected array as described in connection with Fig. 11. In that event, each of the lens blanks (30) of the connected array will have its own flat platform (32) and all blanks and their haptics will be removably fixed by wax, in position for grinding in unison against master grinding member 34, all to the same convex curvature $R_2$. Each resulting integral lens-and-haptic product, after grinding against master 34, will then have the unit appearance depicted in Fig. 15, with a plano-convex lens 30', once the wax connection is dislodged by heat.

Fig. 16 illustrates that conventional glass-lens finishing techniques are also applicable to the generation of concave surfaces, as to radius $R_1$ on the posterior surface of the structure of Fig. 15. To this end, a support member 35 has a concave surface which may be generally spherical to larger radius $R_4$ than (or at offset from) the locus of the $R_1$ concave surface to be ultimately ground, and this surface is characterised by local recesses or pockets 36 of circular configuration to locate the periphery of partially ground lens blank 30' and to provide sufficient depth to clear and thus not to contact the already finished convex surface of radius $R_2$, the pocket (36) cavity is an excellent receptor for mounting wax to fixedly support the blank (30') for concave-surface finishing. As shown, an annular rib 37 rises locally out of the generally spherical support surface of radius $R_4$, to accurately nest all regions of integral haptic connection to the lens blank 30', haptic features 31 being wax-fixed to surrounding concave spherical surface regions, as will be understood.

Fig. 16 additionally shows a master grinding element 38 in offset relation to the concave surface to be ground to radius $R_1$ on the posterior face of lens blank 30'. The master-grinding surface is to the desired radius $R_2$.

And the resulting product, after release of the mounting wax, is as depicted in Fig. 5, except that sectioning should be for glass.

It will be understood that in a manner analogous to that described in connection with Fig. 14, the support 35 of Fig. 16 may provide for multiple support of severably connected blanks 30'. It will also be understood that support 35 lends itself to concave lens-surface grinding, regardless of the curvature or not of the anterior surface of the lens blank or blanks involved.

It will be understood that processed and structures thus-far described meet the above-stated objects, and that they are applicable in the context of a variety of materials and finishing techniques. For example, as to plastics, suitable single-sheet starting material 12 may be selected from available polyimides and polyamides, as well as porous polymethylmethacrilate (HEMA), polyethersulfone, polysulfone, polymethylmethacrilate (PMMA), polyesters, silicones, and polyethyltoluene (PET). Also by way of example, conventional techniques may be employed to build astigmatism-corrective curvatures and axial orientation into the integral haptic and lens structure, complete with a recognition profile or the like from which correct astigmatic-correction axis orientation can be recognised by the physician prescribing and/or installing the structure. Such orientation-refining techniques are described in my copending application Serial No 225 349 (filed January 15, 1981) and in Fig. 17, I show an integrally formed lens 40 and haptic 41 wherein a small asymmetrical fillet 42 provides the means of recognising correct orientation to achieve proper use of the astigmatism-correcting lens prescribed for the particular user.

Fig. 18 illustrates that for any of the haptic configurations contemplated herein, and specifically in the context of the haptic configuration of Fig. 17, the deformation step used to create lens curvature may also be used to impart a haptic curvature generally in accordance with the curvature of the cornea. As noted from Fig. 18, this curvature is generally away from the originally flat nature of the starting sheet of material, but is generally tangent to the plane of the starting sheet in the vicinity of haptic juncture with the central lens element.

The reference to etching herein is to be understood as contemplating any various well recognised selective erosion techniques. For the case of plastic erosion, these techniques include plasma etching, ion milling, and chemical etching. For the case of glass erosion, these techniques include hydrofluoric-acid etching and hydrofluoric-gaseous etching.

The second general illustrative embodiment of the invention (Figs. 19 to 27) is directed to effectively integral structures resembling those of Figs. 1 to 18 but based on i.e., the product of, selectively etched reduction from starting material in the form of flat composite laminated sheet stock, of thickness $T_1' + T_2'$ as shown in Fig. 21, wherein $T_1'$ is the thickness of one (112) of the composite laminations (shown for glass) and $T_2'$ is the thickness of the other (113) of the composite laminations (shown for plastic). The lamination 112 is of thickness to permit ultimate lens formation therefrom, and the lamination 113 is of thickness to serve ultimate haptic formation therefrom; the composite laminated stock is selected for inertness to body fluids.

For convenience, dimensional symbols have been applied to identify: lens 110 diameter at $D_1'$ inner ledge (112) outer diameter $D_2'$, and haptic (111) outer diameter $D_3'$, all having ranges stated above for corresponding dimensions identified in connection with Figs. 1 and 3; substantial fenestration also characterises haptic 111. Lens thickness $T_1'$, is generally in the range of 0.001 to 0.007 inch, for extraocular applications, and in the range of 0.002 to 0.020 for intraocular applications; and haptic thickness $T_2'$ (Fig. 21) is in the order of 0.001 to 0.006 inch for both applications.

To proceed from the sheet 112 of Fig. 21 to the intermediate stage of Fig. 22, I utilise mask and photo-etch techniques which are illustratively described in my U.S. Patent No 4 080 709 and which therefore need not be repeated here. It suffices to indicate that for present purposes, a mask as in Fig. 21B is used for the chemical or other etching of the upper lamination 112 of the composite sheet and that a different mask as in Fig. 22B is used for such etching of the lower lamination 113 of the composite sheet. These two different etchings preferably proceed separately (.e.g., sequentially), thereby achieving full control of the particular depth of erosion desired from each lamination of the composite sheet.

More specifically, the mask pattern of Fig. 21B may be a precise photographic reduction from a master drawing, the reduction being to expose a photosensitive coating of the upper surface of the composite sheet, the exposed coating being thereafter developed to leave a deposited opaque masking pattern 120 (Mask A) on lamination 112 of the composite sheet. Since it is my preference first to etch from one side and then from the other, I fully expose the photosensitive coating on the lower surface of sheet 112, so that upon development, the lower surface is an entirely opaque mask 121 (Mask B) and is thus incapable of permitting an etch from the lower side. With the thus-masked sheet then exposed to an etching environment (for the material of lamination 112), only the areas not opaquely masked will be etched, and this first etching is timed for full penetration of lamination 112 (i.e., to the depth $T_1'$), thus leaving only lamination 113, of haptic thick-

ness $T_2'$, in the etched region. As seen in Fig. 21B, this first mask is characterised for etching exposure of the circular annulus 122, defined internally by a lens-size opaque circular area 123 of diameter $D_1'$ and on the outside by a circumferentially enveloping opaque area. The outer opaque area has a circular inner edge 124 of diameter $D_4'$ slightly greater than ultimate haptic diameter $D_3'$. The product of thus-masked etching is depicted in Fig. 22.

Having etched through the mask 120 of Fig. 21B to the indicated depth $T_1'$, all maskings are stripped, and the specimen is re-coated with photosensitive material. The mask pattern 125 of Fig. 22B is then exposed and developed on the underside of the specimen (becoming Mask D in Fig. 22A), in precise concentric relation with the Fig. 21B exposure and etching, while the upper surfaces of the central lens-blank region 126 and surrounding annular haptic area 127 are totally exposed and developed to produce an unpatterned mask 128 (Mask C) and thus to enable etching exposure (appropriate to the material of lamination 113) only through the Fig. 22B mask (Mask D) on the lower surface of the specimen. This second etching is allowed to proceed fully through the material of lamination 113 (i.e. through ultimate haptic thickness $T_2'$), at which time the intermediate product of Fig. 23 becomes severed from surrounding original sheet material. It is, of course, possible then to strip maskings from the specimen and to proceed thence with lens-finishing. However, it is my preference that the mask of Fig. 22B be formed with at least one later-severable tie-forming opaque connection between the fenestration-defining inner pattern (within diameter $D_3'$) and the inner-edge diameter $D_4'$ of surrounding opaque region 125 of the pattern mask 125.

The inner pattern of the mask 125 of Fig. 22B, i.e, within the diameter $D_4'$ of the inner circular edge of surrounding opaque material 125, will be seen to have the haptic-fenestration detail described in connection with Fig. 1, and identified by numbers 114–115–116 in Fig. 19; therefore in Fig. 22B, corresponding inner opaque parts of this mask (Mask D) are given Fig. 19 reference numbers, with primed notation. However, in the mask of Fig. 22B, the full area within the inner circular confines of ledge 113, i.e., within a circle of diameter $D_5'$, is open, diameter $D_5'$ being less than the diameter $D_1'$ of the lens blank 126, to assure an annulus of retained composite lamination between the etched lens blank 126 and the etched haptic 127.

Having performed the second etch to the pattern of Fig. 22B, all mask deposits are stripped from the partially completed specimen, to permit lens-finishing. In the individually separated specimen situation, each item must be separately handled, but in the edge-interconnected situation, the individual specimens may be more readily handled by mass lens-finishing techniques. One pattern of edge-interconnected specimens is illustrated in Fig. 26, wherein each partially completed specimen (per Fig. 23) is in nested adjacency to and interconnected with six surrounding like specimens; in the fragmentary showing of Fig. 26, three thus-nested partially complete specimens A'-B'-C' are connected, as by a severable tie 130 between specimens A' and B', by a severable tie 131 between specimens A' and C', and by a severable tie 132 between specimens B' and C'.

Fig. 27 is a diagram similar to Fig. 26 but showing a differnt pattern of severable interconnection of partially completed specimens, also lending itself to mass production handling in lens-finishing phases of production, as will later become more clear. In Fig. 27, the pattern of severable interconnection is on discrete parallel alignments of connection. For example, the partially completed specimens E'-F'-G' of one such alignment are severably interconnected at 133 to each other, and the partially completed specimens H'-J'-K' of the next adjacent such alignment are severably interconnected (at 134) but are not connected to the specimens of alignment A'-B'-C' or to those of any other alignment. In other words, the arrangement of Fig. 27 permits automated handling of linear arrays of severably connected specimens.

Returning now to the matter of lens-finishing, and taking the case of having performed etching steps on a starting sheet wherein the lamination 112 is of suitable plastic, the partially completed specimen of Fig. 23 is first accurately positioned in a forming die. Then, the lens shape which may involve an inner concave surface of radius $R_1$ and an outer convex surface of different radius $R_2$ (See Fig. 25), is established by plastic deformation under elevated compressional pressure within the die, resulting in a finished product, as shown in Fig. 25. In this particular finished product, it will be noted that the convex anterior surface of lens 110 is offset from the ledge 113 of effectively integral haptic 111 connection, and that the posterior surface of lens 110 is effectively flush with the haptic, since the haptic thickness $T_2'$ is very small compared to lens thickness $T_1'$.

Although it has been indicated that if the lens-material lamination 112 is a plastic or one of the low-temperature forming glasses, one can compression-form desired curvature(s) in the etched lens blank (126), it is my preference that recognised optical-finishing techniques be employed in the finishing of effectively integral lens-and-haptic configurations wherein the lens-defining lamination 112 is of glass. Figs. 14, 15 and 16 of my said copending application, Serial No. 288 217, illustrate lens-grinding apparatus suit-

able for finishing a glass blank 126 and therefore such apparatus need not now be further described.

Briefly, a partially completed etched product, as in Fig. 23, comprises a lens blank portion 126 of glass and an effectively integrally associated haptic portion 127, and the latter is sufficiently thin to be axially compliant. The flatblank region 126 is mounted to a suitable platform location of a conventional generally truncated spherical multiple-blank support, being removably affixed thereto by wax embedment in accordance with accepted practice, and by wax being also used to removably retain the flexible haptic portions 127 in conformance to curved surfaces of support, adjacent the platform locations. The curvature of radius to which haptic features are thus temporarily conformed is less than or at least relieved from the local of ultimate convex grinding curvature $R_2$ to which the anterior surface of blank 26 is to be ground. For such grinding, a master grinding member having a concave master-grind curvature of radius $R_2$ performs a conventional grinding of the convex anterior lens surface, to radius $R_2$.

As also explained in said copending application, Serial No 288 217, the lens-mounting flat platforms of the lens-grinding support may be at spacings and alignments appropriate to the multiple mounting of severably connected partially completed specimens, for example, a longitudinally connected array as described in connection with Fig. 27. In that event, each of the lens blanks (126) of the connected array will have its own flat mounting platform, and all blanks 126 and their haptics 127 will be removably fixed by wax, in position for grinding in unison against the master grinding member, all to the same convex curvature $R_2$. Each resulting effectively integral lens-and-haptic product, after grinding against the master, will then have the unit appearance depicted in Fig. 24, with a plano-convex lens 110′, once the wax connection is dislodged by heat.

As further explained in said copending application, Serial No 288 217, conventional glass-lens finishing techniques are also applicable to the generation of concave surfaces, as to radius $R_1$ on the posterior surface of the structure of Fig. 24, resulting in a lens 110″ as depicted in Fig. 25.

It will be understood that described composite-laminate processes and structures meet above-stated objects, and that they are applicable in the context of a variety of composite laminate materials and finishing techniques. For example, in the event of a glass-to-plastic composite, the glass lamination 12 should be of optical quality material, and the haptic lamination 13 may be selected from available polyimides and polyamides, as well as porous polymethylmethacrilate (HEMA), polyethersulfone, polysulfone, polymethylmethacrilate (PMMA), polyesters, silicones and polyethyltoluene (PET).

Also by way of example, conventional techniques may be employed to build astigmatism-corrective curvatures and axial orientation into the effectively integral haptic and lens structure, complete with a recognition profile or the like from which correct astigmatic-correction axis orientation can be recognised by the physician prescribing and/or installing the structure. Such orientation-refining techniques are described in my copending application, Serial No 225 349 (filed January 15, 1981), and in Fig. 19, I show by phantom outline 140 that a small asymmetrical fillet may locally characterise fenestration detail, thereby providing the means of recognising correct orientation to achieve proper use of the astigmatism-correcting lens prescribed for the particular user.

While the invention has been described in detail for various illustrative forms and processes, it will be understood that modifications may be made without departing from the scope of the invention.

For example, in either of the techniques illustrated by Figs. 10 and 11 (or by Figs. 26 and 27), the severable tie elements 25–26–27 (25′–26′) and 130–130–132 (133–134) may be characterised by a central "pin-hole" opening external to the perimeter of each of the haptics thereby connected. Such pin-hole opening is illustratively shown at 27′ in Fig. 10 and will be understood in context with other such pin-hole openings (i.e., at other severable connections) to provide a precise optically scannable reference, as when automatically positioning a severably connected array of etched lens blanks with haptics, the positioning being for accurate placement in a multiple-lens press, and/or for precise automated laser cut-off of completed lens-haptic units 10–11 (110–111) from the array.

Also, in connection with the pressing of lens elements as described above, it will be understood that the die used for pressing may be configurated to develop in the lens a rounded outer edge, rather than the sharply defined outer edge shown for example at the circular peripheral edge of the convex surface of lens 10 in Fig. 5. A sharp exposed corner is thereby avoided.

Further, it will be understood that the lens-pressing and lens-grinding operations described are purely illustrative, in that not only may astigmatism corrective curvature be embodied in the pressing die, but so also may other complex curvatures, as for example the curvatures which will embody multifocal (e.g., bi-focal, tri-focal) properties in the lens-blank lamination.

Still further, although the described selective etching steps have been stated to be for times appropriate to achieve etching to stated

depths, as the case may be, it will be understood that the suitable choice of different etching environments for the different lamination materials involved, the timing of etching steps may not be critical. For example, for the case of a glass lamination 112 and for a plastic lamination 113 that is sensitive to sodium hydroxide, the glass etch may be via a hydrogen fluoride to which the plastic lamination is not sensitive, and the plastic etch may be via sodium hydroxide (to which the glass lamination is not sensitive). In such case, it will be appreciated that each etching operation is selectively operable only upon the lamination material which is sensitive to the applicable etching environment, so that an excess timing of either etch is not harmful to the lamination which is not then intended to be etched.

For purposes of simplified presentation, the foregoing description has dealt with the laminations 12–13 of the composite starting sheet as if each lamination were a homogeneous solid, but it will be appreciated that, particularly in extra-ocular applications, a degree of gas and fluid permeability is desired, for enhanced compatability with the human eye. Some of the above-indicated plastic materials exhibit a degree of such permeability, but I prefer to employ exposure to ion, neutron or other particle or X-ray bombardment, as a means of creating a desired mix of holes and hole sizes to thereby enhance permeability, the bombardment being preferably a controlled step applied to the composite sheet, prior to the erosion processes described above; alternatively, the bombardment to enhance permeability may be performed after masking and just before etching, or after the lens-finishing step. To provide a degree of gas and fluid permeability for applications in which glass is used rather than plastic, it can be noted that glasses with such permeability now and are available from Corning Glass Works, Corning, New York.

Also, for simplified presentation, the description of the invention has been concerned primarily with the lens element and its formation, so that it will be understood that conventional optical coating and other finishing steps desired for other lens configurations are equally applicable for the present case. Another such finishing step may be a third etch (without mask) to improve edge geometry and avoid sharp edges in the final product.

CLAIMS

1. A unitary lens and haptic construction integrally formed by selective erosion from the same sheet of starting material, comprising a relatively thick rigid central lens component having a generally circular periphery, and a relatively thin pliant generally annular outer haptic component extending radially outward of and distributed circumferentially about the lens periphery.

2. The construction of claim 1, in which said sheet is a single composite laminate of two different ply materials at least one of which ply materials is transparent and of optical quality and constitutes a relatively thick rigid first ply of said single sheet, the other ply material of said laminate being relatively thin compared to the thickness of said first ply.

3. The construction of claim 1 or claim 2, wherein the lens-component diameter is in the range of 5 to 8 mm.

4. The construction of claim 1 or claim 2, wherein the haptic-component thickness is in the order of one thousandth of an inch.

5. The construction of claim 1, wherein one surface of the haptic component is substantially flush with the corresponding surface of the lens component.

6. The construction of claim 1, wherein both surfaces of the haptic component are axially inwardly offset from both surfaces of the lens component.

7. The construction of claim 1 or claim 2, wherein said construction is one of a plurality of like constructions in laterally offset relation and formed from the same single plastic sheet, being integrally but severably joined to each other at local proximity of their respective haptic components.

8. The construction of claim 7, wherein a short integrally formed tie between adjacent haptic components is the means of severable connection.

9. The construction of claim 8, wherein a locating aperture characterises a region of said tie external to the periphreal contour of each of the adjacent haptics thereby severably joined, whereby lens blanks associated with the severably connected haptics may be accurately positioned via such apertures, as for lens-finishing alignment and orientation, and for cut-off.

10. The construction of claim 2, in which said first ply is of glass, and said other ply is of plastic.

11. The construction of claim 2, in which said first ply is of a first plastic material and said other ply is of a second plastic material.

12. The construction of claim 2, in which said composite laminated sheet is transparent.

13. The construction of claim 1 or claim 2, wherein the pattern of haptic formations includes an observable asymmetric indicium which establishes a recognisable reference orientation, and wherein the central lens component includes an astigmatic-correction curvature having an axis orientation of predetermined angular orientation with respect to said reference orientation.

14. The method of making the construction of claim 1, which comprises selecting the sheet of transparent material of thickness at

least sufficient to accommodate ultimate thickness of the lens component, masking one side of the sheet to permit selective removal of material in the generally annular included area of the haptic component to the exclusion of the central area of the lens component, masking the other side of the sheet to permit selective removal of material to define haptic leg formations within the generally annular included area of the haptic component to the exclusion of the central area of the lens component, subjecting both masked sides of the masked sheet to an eroding environment, the erosion exposure of said one side being to the depth extent of defining the relatively thin ultimate haptic thickness, and the erosion exposure of said other side being to the depth extent of at least said ultimate haptic thickness, removing the mask, and thereafter forming a lens curvature in at least one of the surfaces of the lens component.

15. The method of claim 14, wherein the transparent material is a plastic and said erosion exposure is by chemical etching.

16. The method of claim 14, wherein the transparent material is a plastic and said erosion exposure is by plasma-ion discharge.

17. The method of claim 14, wherein the lens-curvature forming step is performed by die compression.

18. The method of claim 14, wherein the transparent material is glass and said erosion is by hydrofluoric-acid etching.

19. The method of claim 14, wherein the transparent material is glass and said erosion is by hydrofluoric gaseous etching.

20. The method of claim 14, wherein at least part of the etching occurs simultaneously from both sides of said sheet.

21. The method of claim 14 or claim 17, wherein etching occurs sequentially first from one side of said sheet via the involved mask, and thereafter from the other side of said sheet via the involved mask.

22. The method of claim 21, in which said first etching step occurs in the circumstance of full masking of said other side, and in which the subsequent etching step occurs in the circumstance of full masking of the first-etched side.

23. The method of claim 14, wherein the transparent material is glass, and the lens-curvature forming step is performed by conventional lens grinding techniques while retaining adjacent haptic formations in a deformed position out of the locus of ultimate grinding curvature of the involved surface.

24. The method of masking the construction of claim 1, which comprises selecting the sheet of transparent material of thickness at least sufficient to accommodate ultimate thickness of the lens component, selecting a circular area within said sheet for ultimate lens-perimeter definition, forming a lens curvature within and limited by said selected circular area, masking one side of the sheet to permit selective removal of material in the generally annular included area of the haptic component to the exclusion of the central area of the lens component, masking the other side of the sheet to permit selective removal of material to define haptic leg formations within the generally annular included area of the haptic component to the exclusion of the central area of the lens component, subjecting both masked sides of the masked sheet to an eroding environment, the erosion exposure of said one side being to the depth extent of defining the relative thin ultimate haptic thickness, and the erosion exposure of said other side being to the depth extent of at least said ultimate haptic thickness, and removing the mask.

25. The method of claim 14 or claim 24, wherein said unitary lens and haptic construction is one of a plurality of like-constructions formed concurrently from said sheet in side-by-side adjacency.

26. The method of claim 25, in which adjacent like constructions are formed in severably connected array.

27. The construction of claim 1 or claim 2, wherein the pattern of haptic formations includes an observable asymmetric indicium which establishes a recognisable reference orientation, and wherein the central lens component includes an astigmatic-correction curvature having an axis orientation of predetermined angular orientation with respect to said reference orientation.

28. The construction of claim 1, in which said single sheet is initially flat and deformed into bowed curvature away from the initial flat of said sheet, the arc of the bow being substantially tangent to the initial flat of said sheet of haptic juncture with the lens component.

29. The method of making the construction of claim 1, wherein the transparent material is glass, which method comprises first using photo-etch techniques to selectively erode a haptic annulus surrounding the circular edge profile of the lens component and to thereby define an intermediate product having the ultimate relatively thin compliant nature and fenestration detail of the haptic, then mounting the lens component of the intermediate product for conventional lens finishing to a desired ultimate lens curvature, the mounting being to secure the lens component in a holder and also to compliantly bend and secure the haptic structure associated with the lens component, the secure bent haptic structure when thus mounted being in offset relation to the geometrical surface to which conventional grinding is to finish the lens component.

30. The method of making the construction of claim 2, which comprises selecting the composite laminated sheet for thickness in

said first ply at least sufficient to accommodate ultimate thickness of the lens component and for thickness in said other ply at least sufficient to accommodate ultimate thickness of the haptic component, masking the outer surface of said first ply with a first pattern to determine selective removal of first ply material in the generally annular included area of the haptic component to exclusion of a central circular area sized for area accommodation of the lens component, masking the outer surface of said other ply with a second pattern that is in concentrically aligned register with the centre of the first pattern, the second pattern being configurated to mask a narrow annulus of rim overlap with said central circular area and to mask haptic outward leg-defining formations contiguous to said narrow annulus and within the generally annular included area of the haptic component, subjecting each of the masked sides of the composite sheet to an eroding environment which is specific to the applicable masked ply, the erosion exposure of the masked first ply being sufficient to erode through first-ply thickness the erosion exposure of the masked other ply being sufficient to erode through other-ply thickness, removing the masks, and thereafter forming a lens curvature in at least one of the surfaces of the lens component.

31. The method of claim 30, in which one of said pattern-masking steps and the erosion step associated therewith are undertaken before performing the other pattern-masking step and its associated erosion step.

32. The method of claim 30, in which the erosion environment specific to the material of said first ply is selected for other-ply insensitivity thereto.

33. The method of claim 30, in which the erosion environment specific to the material of said other ply is selected for first-ply insensitivity thereto.

34. The method of claim 32, in which said first ply is of glass and said other ply is of plastic, the first-ply erosion exposure containing hydrogen fluoride as an essential component.

35. The method of claim 33, in which said first ply is of glass and said other ply is of plastic, the other ply erosion exposure containing sodium hydroxide as an essential component.

36. The method of claim 30, in which the material of at least one of said laminations is a plastic and the erosion exposure thereof is to chemical etching.

37. The method of claim 30, in which the material of at least one of said laminations is a plastic and the erosion exposure thereof is to a plasma-ion discharge.

38. The method of claim 30, in which the material of at least one of said laminations is a glass and the erosion exposure thereof is to hydrofluoric-acid etching.

39. The method of claim 30, in which the material of at least one of said laminations is a glass and the erosion exposure thereof is to hydrofluoric gaseous etching.

40. The method of claim 30, in which the first-ply material is a plastic and the lens-curvature forming step is performed by die compression.

41. The method of claim 30, in which the first-ply material is a glass and the lens-curvature forming step is performed by conventional lens-grinding techniques while retaining adjacent haptic formations in a deformed position out of the locus of ultimate grinding curvature of the involved surface.

42. The method of claim 30, in which the first-ply erosion occurs in the circumstance of full masking of other-ply side, and in which the other-ply erosion step occurs in the circumstances of full masking of the first-ply side.

43. The construction of claim 10, in which the glass ply is gas and fluid permeable.

44. The construction of claim 10 or claim 11, in which the plastic is gas and fluid permeable.

45. The method of claim 30, in which the material of at least one of said laminations is a plastic and the erosion exposure thereof is to X-ray radiation.

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